Integrated management of wastewater and domestic organic waste in small communities

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Abstract

The feasibility of the combined treatment of domestic wastewater and domestic organic waste (DOW) generated in a small community (2,000 population equivalent) was evaluated. Different schemes were investigated for the co-treatment of domestic wastewater and DOW by considering the use of food waste disposers at different integration levels (100% and 50%) as well as the source collection and treatment of DOW. The examined technologies were the upflow anaerobic sludge blanket (UASB) for energy recovery coupled to a sequencing batch reactor (SBR) to remove nutrients, the anaerobic membrane bioreactor without any post treatment of the effluent, the fermentation process of DOW to provide a liquid rich in volatile fatty acids which can be used as an external organic carbon source for nutrient removal in the SBR as well as to increase biogas production in the UASB process and the composting unit for the stabilisation of the generated sludge. The applied treatment schemes result in valuable products, such as electricity and heat from the combustion of the biogas and soil conditioner from the sludge treatment. The carbon source provided by the DOW can be used to remove nutrients in the SBR and increase biogas production in the UASB. The application of nitritation/denitritation as opposed to conventional nitrification/denitrification saves significant amount of carbon source that can be applied to the UASB process increasing the energy recovery or can be used to remove phosphorus. When conventional denitrification is applied the carbon source provided from the fermentation liquid of FWDs is enough only to remove nitrogen.

Keywords

Small and decentralised treatment systems; environmental profile; food waste disposer; nitrogen removal; resource recovery.

Introduction

In small and decentralized communities the local treatment of domestic wastewater and domestic organic waste (DOW) can be beneficial, decreasing the cost for the development and operation of long sewer networks and pumping stations as well as the transportation of DOW to centralized facilities (Massoud et al., 2009). Furthermore, the potential co-treatment of DOW and domestic wastewater can be a sustainable option leading to energy and materials recovery with significant environmental and economic benefits for the community. In this context, treatment processes that convert waste into resources currently constitute a challenge (Nakakubo et al., 2012). Effective waste and wastewater treatment and resource recovery can be accomplished by applying innovative and conventional anaerobic and aerobic processes, in order to address site specific conditions for wastewater treatment (Katsou et al., 2014). Small and decentralised systems are not only a long-term solution for small communities, but also a reliable and cost effective option (Massoud et al., 2009).

Food waste disposers (FWDs) can be applied for the collection of source separated DOW within households (Battistoni et al., 2007). Their use can be an interesting option to integrate the management of domestic wastewater and household organic waste in small and decentralised communities. The application of FWDs decreases the frequency of transportation of DOW and produces less odours compared with the technologies which apply separate collection and transportation of DOW to centralized treatment facilities (Marashlian and El-Fadel, 2005). The alternative to FWD is source separation and collection of DOW which is then sent to a waste treatment facility. In both cases, landfilling of DOW is avoided, which is of the priorities of the Directive 1999/31/EC.

In this work alternative schemes were evaluated for the co-treatment of DOW and domestic wastewater considering a small community. The target was to identify the most efficient scheme in terms of energy recovery, the production of high treated effluent quality and the production of soil conditioner adequate for soil application.

Materials and methods

The main goal of this study was to evaluate and compare the performance of alternative schemes for the combined management of wastewater and DOW in a small and decentralised community of 2,000 PE. Alternative DOW and wastewater treatment schemes were considered and thus different scenarios were developed. Table 1 shows the different scenarios which were considered. The technologies which were considered were the following:

- Upflow anaerobic sludge blanket (UASB) for the anaerobic treatment of wastewater resulting in energy recovery
- Sequencing batch reactor (SBR) for the post treatment of the UASB effluent to remove nutrients and produce a treated effluent which can be reused.
- Anaerobic membrane bioreactor (AnMBR) for the treatment of wastewater to remove COD and recover energy
- Fermentation for the treatment of DOW and primary sludge (if implemented) to produce fermentation liquid rich in volatile fatty acids (VFAs) that can be used as external carbon source for the processes of denitrification and enhanced biological phosphorus removal. The surplus of fermentation liquid can be fed to the UASB process to increase biogas production.
- Composting of the solid fraction of the fermented waste and of the excess sludge in order to produce a stabilized solid product which can be applied to land.

Table 1: Summary of the different scenarios which were considered

Scenario	Technology for wastewater	Technology for DOW	Nitrogen removal	Phosphorus removal	Where is carbon source applied
SC1	UASB-SBR	SS, Fermentation & Composting	Nitritation/ denitritation	No	SBR for N removal, UASB for biogas increase
SC2	UASB-SBR	SS, Fermentation & Composting	Nitrification/ denitrification	No	SBR for N removal
SC3	UASB-SBR	SS, Fermentation & Composting	Nitritation/ denitritation	EBPR	SBR for nutrient removal, UASB for biogas increase
SC4	UASB-SBR	100% FWDs, Fermentation, Composting	Nitritation/ denitritation	No	SBR for N removal, UASB for biogas increase
SC5	Primary sedimentation, UASB-SBR	100% FWDs, Fermentation, Composting	Nitrification/ denitrification	No	SBR for N removal
SC6	Primary sedimentation, UASB-SBR	50% SS, 50% FWDs, fermentation, composting	Nitritation/ denitritation	No	SBR for N removal, UASB for biogas increase
SC7	Primary settling, AnMBR	SS, fermentation, composting	No	No	AnMBR for biogas increase
SC8	Primary settling, AnMBR	100% FWDs, Fermentation, Composting	No	No	AnMBR for biogas increase
SC9	Primary settling,	50% SS, 50% FWDs,	No	No	AnMBR for biogas increase

AnMBR	fermentation, composting	

Concerning the DOW and wastewater collection scheme, three different options were considered: (1) the separateDOW collection through source separation (SS) and transportation to the plant, (2) the use of FWDs (100% integration) where the DOW is pumped along with the wastewater to the plant and (3) 50% integration of FWDs coupled with SS and transportation of the remaining 50% of DOW to the plant. The target biological nutrient removal processes were conventional nitrification/denitrification, short-cut nitrification-denitrification (nitritation/denitritation) and enhanced biological phosphorus removal. Table 2 summarizes the most important assumptions that were considered for domestic wastewater, source separated DOW and FWDs.

Table 2. Main characteristics of wastewater (WW), source separated domestic organic waste (SS-DOW)and FWDs

Parameter	Unit	Quantity
Inhabitants	PE	2,000
Wastewater		
Production	L/PE·d	200
Flow	m^3/d	400
COD	gCOD/PE·d	120
N	gN/PE·d	12.0
P	gP/PE·d	1.8
SS-DOW		
Production	kgDOW/PE·d	0.25
Flow	kg/d	500
Total solids (TS)	%	25
COD	mgCOD/gTS	1200
N	mgN/gTS	25
P	mgP/gTS	3
WW+FWDs (100% integration)		
Flow	m^3/d	404.5
COD	$gCOD/PE^{-1}\cdot d^{-1}$	215
N	gN/PE·d	14.1
P	gP/PE·d	2.1

Mass balances were developed based on real data from the operation of pilot plants located in North Italy, literature data and reasonable assumptions (Katsou et al., 2014). This study included the treatment of wastewater and DOW either separately or as a single stream.

Results and discussion

Table 3 summarizes the main parameters which were determined for the different scenarios. The highest methane generation and thus energy recovery was obtained in SC7-9 where the AnMBR was applied without any post treatment of the AnMBR effluent. This is reasonable, since the avoidance of nutrient removal results in feeding all the produced fermentation liquid to the anaerobic process. However, this was done at the expense of the treated effluent quality which is characterized by high nutrient levels. SC7-9 can be applied in cases where the discharge/reuse of the treated effluent does not have any nutrient limits. The implementation of the two different waste management schemes (i.e. FWDs versus SS) resulted in similar energy recovery (slightly higher for FWDs). When the nitritation/denitritation process is applied, the fermentation liquid is enough to be used for EBPR or to be supplied to the UASB process to increase biogas production. In the latter case, 70% of the fermentation liquid is enough to cover the carbon requirements of denitritation in the SBR, while the remaining 30% is supplied to the UASB process. When FWDs are applied with 100% integration in the community, 60% of the fermentation liquid is enough to remove nitrogen via nitrite. When conventional nitrification/denitrification is applied, all the carbon source should be provided for the denitrification process and thus there is no excess carbon source to be applied to the UASB. Furthermore, there is no carbon source available to accomplish EBPR.

Table 3. Summary of the most important parameters for the 4 examined scenarios

Parameter	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9
Methane produced (m^3/d)	67	61	61	71	60	66	96	100	93
Electrical energy produced (kWh/d)	249	225	225	264	223	244	354	371	345
Thermal energy produced (kWh/d)	392	354	354	416	350	384	557	583	542
Fermented liquid sent to SBR (%)	70	100	100	60	97	55	0	0	0
Fermented liquid sent to UASB or AnMBR (%)	30	0	0	40	3	45	100	100	100
Energy requirements for SBR aeration (kWh/d)	132	155	130	137	161	134	-	-	-
Energy for composting (kWh/d)	21	23	22	24	25	24	12	15	16
N treated effluent (mg/L)	9.6	13.5	9.6	9.9	10.1	9.6	62.9	65.9	64.0
P treated effluent (mg/L)	7.5	7.3	1.1	8.0	7.9	7.8	8.4	9.4	9.0
COD treated effluent (mg/L)	36	41	41	55	68	21	81	83	78
N end compost (% w/w)	2.1	2.2	2.2	1.6	1.7	1.7	1.4	1.0	1.2
P end compost (% w/w)	0.4	0.4	1.1	0.3	0.3	0.3	0.3	0.3	0.3

To conclude the implementation of FWDs and nitritation/denitritation are the most favourable options (SC4) when nutrient removal is also required. If nitrogen removal is only required than a significant part (40-45%) of the fermentation liquid can be provided to the UASB process to increase energy recovery.The integration of FWDs within wastewater results in a significant increase of the COD load of the wastewater, provided that the integration level of FWDs is significant.

Conclusions

The investigation of the potential co-treatment of DOW and domestic wastewater showed that this scheme is feasible and beneficial for small communities. If nutrient removal is required then nitritation/denitritation is the most favourable option since the fermentation liquid is enough to remove nitrogen and phosphorus or to remove nitrogen and provide the excess 40-45% of the carbon source to the UASB process in order to increase energy recovery. When the conventional nitrification/denitrification process is applied the produced carbon source is enough only to cover nitrogen removal.

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